(NASA-TM-111071) PERFORMANCE TESTING OF HIGHLY LOADED SINGLE STAGE OXIDIZER TURBINE WITH VOLUTE MANIFOLDS (NASA. Marshall Space Flight Center) 6 p

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PERFORMANCE TESTING OF HIGHLY LOADED SINGLE STAGE OXIDIZER TURBINE WITH VOLUTE MANIFOLDS

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Baseline air test results from a highly loaded single stage oxidizer turbine, called the Oxidizer Technology Turbine Rig (OTTR), will be presented. This turbine has been designed to support the development of advanced turbines for future liquid rocket engines. The OTTR (Fig. 1,2,3) is a scaled model of the Gas Generator Oxidizer Turbine (GGOT) developed by the Turbine Technology Team within the Consortium for Computational Fluid Dynamics Applications in Propulsion Technology. The GGOT is a highly loaded single stage oxidizer turbine which uses inlet and exit volutes to provide optimum performance in a compact configuration. This aerodynamic design was incorporated into a turbine test rig, the OTTR, to be tested in the Marshall Space Flight Center's cold air flow Turbine Test Equipment (TTE). The rig was heavily instrumented to obtain a benchmark quality data set. The data set will be used to evaluate the aerodynamic performance of the turbine and the volutes and to validate various Computational Fluid Dynamics (CFD) codes used in the turbine design phase. This work is being done to advance liquid rocket engine turbine design technology and to demonstrate the benefits of CFD application to component design.

The test is being conducted in the MSFC air flow Turbine Test Equipment. The TTE is a blowdown facility which operates by expanding high pressure air (420 psig) from one or two 6000 cubic feet air tanks to atmospheric conditions. Air flows from the storage tanks through a heater section, quiet trim control valve, and a calibrated subsonic mass flow venturi. The original facility piping then continues in the axial direction with flow going through the plenum section, test model, backpressure valve, and exhausting to atmosphere (Fig. 4). The facility piping, however, has been modified for the OTTR to provide tangential flow into the inlet volute and to accommodate the tangential flow leaving the exit volute. A new 8 inch pipe has been routed from the tee below the pressure relief valve to supply air to the model. The model is structurally mounted on the plenum contraction flange with a connection that blanks off the plenum air supply. The model discharges into a new 10 inch exhaust pipe which is connected to the 10 inch plenum exhaust piping. Flow straighteners are included in the inlet pipe after the last turn. Two sections containing four bosses (2 inch diameter) each are also included for facility measurements and seeding for Laser Doppler Velocimeter (LDV) measurements.

This equipment can deliver 220 psia air for run times from 30 seconds to over 5 minutes. The run times increase significantly as the inlet pressure is lowered (one hour or more at 50 psia). The heater allows a blowdown controlled temperature between 530° R and 830° R. The TTE has manual set point closed-loop control of the model inlet total pressure, inlet total temperature, shaft rotational speed, and pressure ratio. In addition to these control parameters, the facility can accurately measure mass flow, torque, and horsepower. The associated data system is capable of measuring 512 pressures, 120 temperatures, and various model health monitoring variables.

The objectives of the OTTR test program are very broad due to the requirement to use the data not only for performance evaluation but also for CFD code validation. Performance evaluation for the program includes the turbine, the inlet volute, an oversized square exit volute, a circular exit volute, and a diffuser section. The oversized square exit volute is being used for the baseline test so that the turbine can be evaluated over a large off-design envelope. The square design was used to increase the volute flow area. This prevents the flow from choking in the exit volute before it chokes in the turbine at the off-design points. The results of the baseline test using the square exit volute will be presented in this paper.

Many detailed measurements are being made to meet the objectives of obtaining data for performance evaluation and CFD code validation. These measurements include:

(1) Turbine inlet and exit radial and circumferential pressure, temperature, and flow angle contours.
(2) Circumferential static pressure gradients in the inlet and exit volutes.
(3) Turbine flowpath static pressure drops.
(4) Stator airfoil static pressure distributions.
(5) Velocity profiles, turbulence intensities, and boundary layer thicknesses at the inlet and exit of the turbine and at various stations in the inlet and exit volutes.

To obtain the above measurements and to monitor the model's health, the OTTR contains the following types of instrumentation:

(1) Pressure (total and static)
(2) Temperature
(3) Flow Angle
(4) Laser Window
(5) Shaft Speed Pickup
(6) Accelerometer.

The model instrumentation was planned so that the performance of the inlet volute, turbine, exit volute, and diffuser sections could be evaluated separately. To accomplish this, inlet and exit planes were defined for each of these sections. An overview of the model instrumentation is given in Table 1.

The baseline test of the OTTR in the TTE is currently underway. Detailed measurements have been obtained at the inlet to the inlet volute, through the inlet volute, at the turbine inlet, and through the turbine. Measurements are currently being made at the turbine exit plane. Once the turbine exit plane is well understood, the exit volute and diffuser sections will be studied. Testing is scheduled to continue through January 1995. Data obtained to meet the objectives of the baseline test will be presented in the paper. Since the testing and data analysis are not complete, no data will be given here. Also, due to time and space constraints, laser doppler velocimetry measurements of velocity profiles, boundary layer thicknesses, and turbulence intensities may not be included in the paper.

The design of the OTTR presents many challenges for obtaining accurate test results. The volutes cause gradients in pressure and temperature at the turbine inlet and exit. The high Mach number, high swirl flow at the turbine exit presents particularly difficult measurement demands. For overall performance calculations, a good overall average temperature and pressure (total and static) is needed at the turbine inlet and exit plane. To accurately determine the turbine average inlet and exit pressure and temperature, a sufficient number of measurements must be made at the proper locations and these measurements must be averaged correctly. This requires careful probe calibration and data analysis techniques. Probe calibration is also very important for obtaining the detailed pressure, temperature, flow angle, and velocity profiles needed for CFD code validation. An uncertainty analysis section will be included in the paper that addresses these issues.

Table 1. Instrumentation Overview

Inlet Volute:
Inlet--2 bosses 90° off. Circumferential wall static pressures--10 planes. 2 laser window locations at 4 planes.
Turbine Inlet and Exit:
4 total pressure rakes (5 probes each). 4 total temperature rakes (5 probes each). 2 flow angle rakes (5 probes each). 2 auto-nulling cobra probes with radial actuators. Each can traverse 90° circ. Maximum of 8 rakes and 2 cobra probes can be inserted at once. Automatic circumferential traverse.
Turbine:
Inner and outer wall static pressures--7 planes. Vane surface static pressures: 4 circ. locations at 50% span, 1 circ. location at 10% span, 1 circ. location at 90% span. Disk cavity static pressures: 4 front, 4 rear. Disk cavity total temperatures: 2 front, 2 rear.
Exit Volute:
Circumferential wall static pressures--9 planes. Exit total pressure rake (9 probes) on manual circ. traverse (30° increments). 2 laser window locations at 4 planes.
Diffuser:
Static pressures--10 axially and 4 exit. Exit total pressure rake (9 probes) on manual circ. traverse (30° increments).
Miscellaneous:
2 speed pick-ups. Accelerometers: 2 horizontal, 2 vertical. Contoured blank plugs for all bosses. Health monitoring instrumentation.

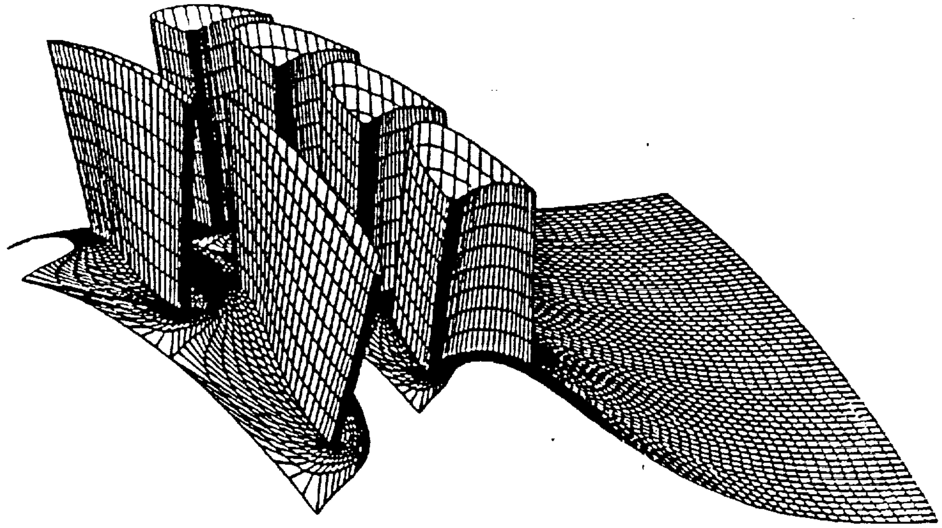


Fig. 1. OTTR Vanes and Blades (viewed from front)

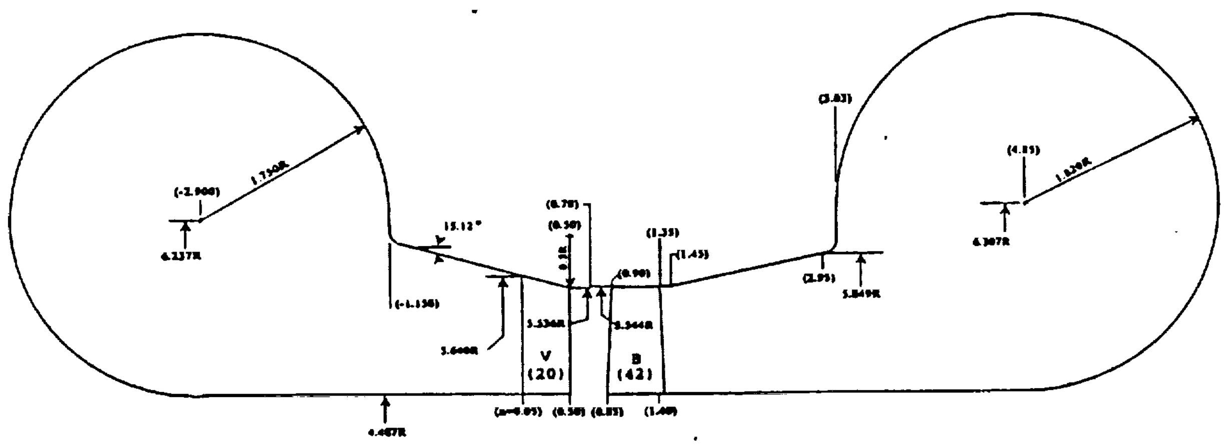
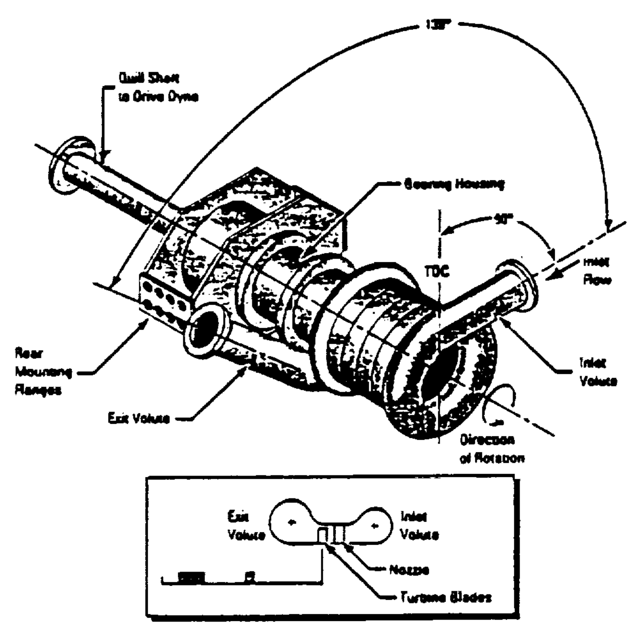


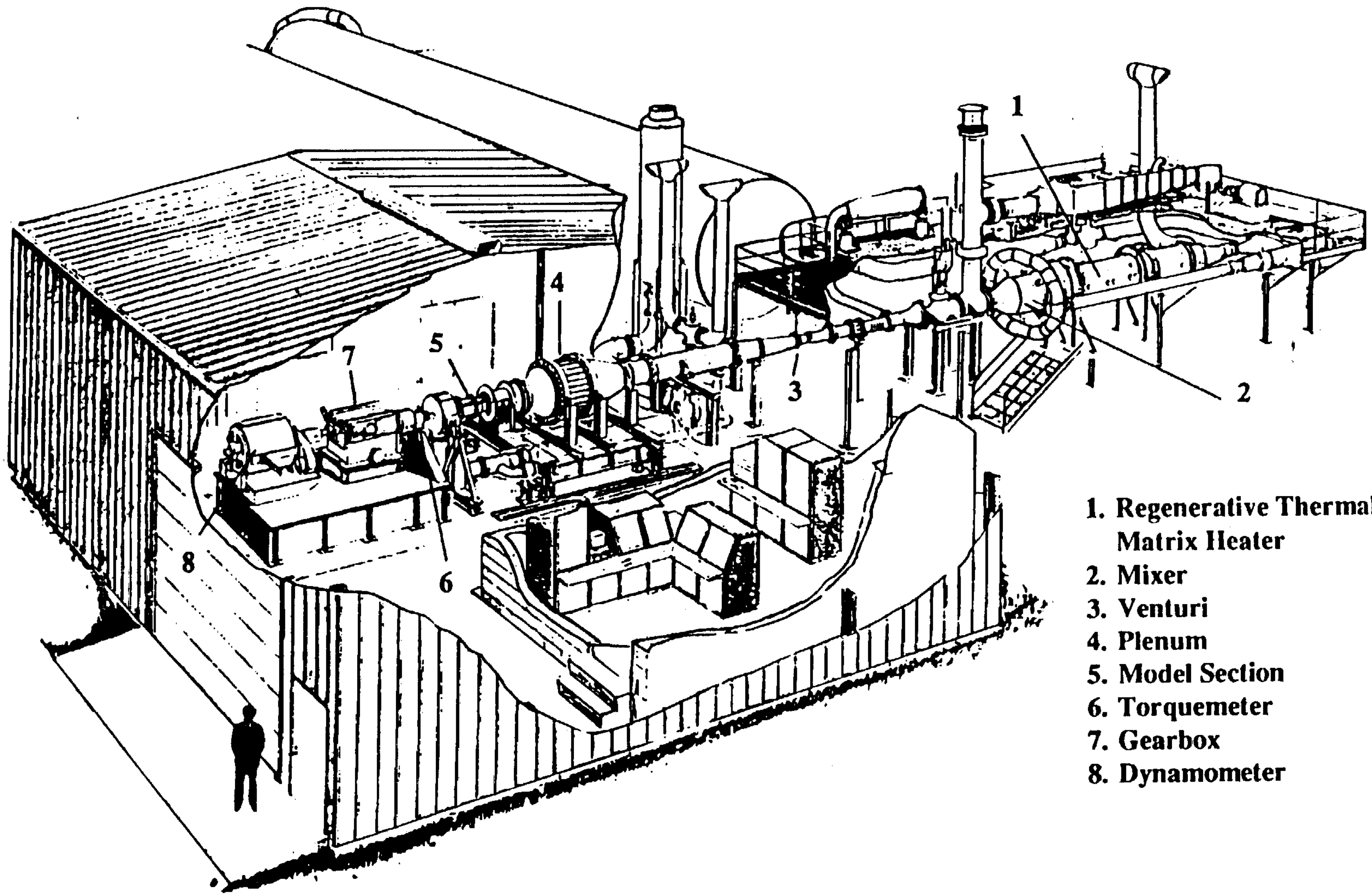
Fig. 2. OTTR Flowpath

Axial Location - ( )



TDC—Top Dead Center

Fig. 3. Schematic of OTTR



1. Regenerative Thermal Matrix Heater
2. Mixer
3. Venturi
4. Plenum
5. Model Section
6. Torquemeter
7. Gearbox
8. Dynamometer

Fig. 4. Schematic of TTE